Systems Engineering Capstone Marketplace Pilot

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BACKGROUND

The goal of this pilot project was to determine the feasibility of and requirements for a systems engineering capstone experience marketplace environment. We hope to increase the number of systems engineering capstone projects conducted at universities each year by facilitating the cooperation and coordination of teams of students from multiple campuses on individual projects. This has the potential for increasing student engagement, as it enables student participation at schools that might not otherwise have the faculty interest or resources to undertake such projects. It also makes it easier to conduct projects of greater size and complexity where the benefits of a systems engineering approach are more visible.

The program was implemented in three sequential phases over a 12-month period:

During Phase 1/Startup (September 1, 2012-January 31, 2013) the software for the marketplace registry was prepared, candidate projects were entered into the registry, students entered their qualifications into the registry, students volunteered for projects, project teams were created, and projects were started.

During Phase 2/Project Completion (February 1, 2013-June 30, 2013) student projects completed their work and submitted final deliverables to stakeholders, and stakeholders and faculty performed assessments of student work.

During Phase 3/Guideline Preparation (July 1, 2013-August 31, 2013) all participating faculty distilled the lessons of the distributed team and prepared guidelines for future instances of the marketplace, and suggested modifications were made to the marketplace software.

PHASE 1/STARTUP EXPERIENCE

This section of the report summarizes progress made during the first phase of the project.

PARTICIPATING SPONSORS AND PROJECTS

Project ideas and potential sponsors for student projects were found through a combination of search strategies: sponsors and mentors of capstone projects at RT-19 and RT-19A participating institutions, candidate leads suggested by SERC researchers, national laboratory contacts suggested by members of the OASD(R&E) STEM Development Office, and personal networking.

Although there was little time to prepare project proposals, 9 separate projects were collected and presented to student participants through the registry website:

Sponsor	Project
Advertising.com	Mobile advertising effectiveness
FAA	Airport operation and safety
Lincoln Laboratory	Mobile communication system for crisis situations
NASA	*Water vapor radiometer for a satellite
US Army	*Monitoring subsystem for a training system
US Navy	*Safe, affordable ferry for transportation in a developing country
US Navy	*Components for a disaster relief kit
US Navy	Power generator using energy from coastal waves
Videology	Video advertising forecasting capabilities

The projects annotated with leading asterisks were selected by student teams. Two of those projects, the ferry for a developing country and the components for a disaster relief kit, were merged into one project. The monitoring subsystem project was executed by multiple teams in parallel.

This list was more than adequate to satisfy student needs, as all participating students were able to find projects of interest. Several other project leads were pursued that did not yield proposals in time for the pilot but that may lead to projects in future years.

Participating Schools

Participation in this pilot project was limited to schools that had already participated in RT-19 or RT-19A, or were members of the SERC. An invitation to join the pilot was distributed to all of those schools, and several follow-up communications were made to promote interest and participation.

5 schools joined the project:

School	Students
Missouri University of Science and Technology (MUST)	36 graduate students in systems engineering on 8 separate teams
Southern Methodist University (SMU)	3 undergraduate students in electrical engineering 4 undergraduate students in computer science
Stevens Institute of Technology	4 undergraduates in engineering management 2 undergraduate students in naval engineering
University of Alabama in Huntsville (UAH)	4 undergraduates in aerospace engineering
University of Hawaii at Manoa	4 graduate students in information technology

Many potential candidate schools and departments reported that it was already too late to consider participation by the time they were contacted. Nevertheless, the 5 schools that did join provided a variety of institution types and partnership arrangements. Several schools responded with interest in participating in a marketplace system in future years.

Some schools start creating teams during the spring semester, some do it over the summer, and some schools have to wait until the fall term when students come back to campus. So the window needs to open during the spring academic term (before April) and close at the start of the fall term (September 15). Ideally, some project opportunities would be identified as early as January.

Experience with Website Registry System

The software for the website registry was adapted from a system developed at Stevens Institute by a previous student capstone team. That system was designed to allow students to form multidisciplinary teams through self-selection: students volunteered for proposed projects posted on the website, faculty supervisors reviewed those student applications and approved project participation. There were mechanisms in place for students to post comments on proposed projects and for new projects to be proposed by faculty or students.

Some of the features of the original system were specific to the Stevens environment. For example, in preparing their personal profiles students selected their academic major from a list of majors available at Stevens. This same list was used to allow project proposers to specify types of needed students. Security and access to the website assumed that all users would be members of the Stevens community and would have accounts on the Stevens computing network. All of these features were removed or adapted for use by a wider community.

The resulting system provided facilities to display project proposals and to register students. Instead of a web-based profile entry system students were asked to fill out a form that they uploaded. The principal investigator had the ability to see all the project choices that students made, but students, faculty and sponsors were only allowed to see the project proposals.

Students used the system to find projects. The project descriptions were short text narratives without any graphics, but with pointers to other websites with more information in some cases. Since students were not able to see whether other students had already selected projects, we did not get a chance to test whether that would have influenced their choices. We also did not test the capability for project sponsors to review and approve student applicants. Instead, faculty at each school reviewed their student applicants.

TEAM FORMATION

Student teams were formed in different ways. At two schools faculty selected projects and assigned students to teams. At two other schools students were allowed to choose their own projects. In all cases faculty were involved in final selection of projects and team members. At Stevens two teams were initially formed to work on independent projects. Faculty then realized that the two teams would work more effectively on a combined project. A team from the University of Alabama in Huntsville also joined the same project.

As mentioned earlier, we were not able to test students' ability to form teams independently through the website registry system. Instead faculty guided or assisted students in the formation of teams. This is an expense (in effort) that we hope to reduce in the future through the marketplace system. Part of the expense is the effort required to collect information from the students (e.g., interests and abilities, preferences for other teammates). Another part is matching students to teams and then dealing with complaints/problems that require switching assignments. Depending on the school, these two processes can consume many hours distributed over a couple months. It is not so much the total time involved that matters, but the nuisance of dealing with a noisy process. Letting the students form their own teams eliminates much of this, though there will always be some team-forming problems that faculty will need to solve. Letting students form their own teams also encourages them to accept responsibility for their own problems. We want engineering students to learn some of the organizational and social skills involved in this process.

Student Team Progress

Each of the student teams made good progress in their first semester. Although almost all of the teams started later than they had originally intended, they all made up lost time and/or re-scoped their projects to be on schedule. In some cases teams were held up by delays or changes in funding that caused them to rescale their projects. Each of the projects used good systems engineering practices.

Student Interaction Between Teams

Some of the student teams had frequent contact with one another, while others did not. The team from the University of Hawaii had originally intended to work with both the SMU team and the MUST team. Neither of those partnerships developed. The Stevens and UAH teams were in constant contact throughout the first semester. They met weekly by Skype and exchanged email regularly.

This section of the report summarizes progress made during the second phase of the project.

NASA WATER VAPOR RADIOMETER PROJECT

This project engaged 1 team of students from SMU: 3 undergraduate students in electrical engineering and 4 undergraduate students in computer science. The team successfully designed a virtual radiometer to meet the stated needs of NASA for their CHARM (CubeSat Hydrometric Atmospheric Radiometer Module) project.

The team had originally planned to collaborate with a team of students at the University of Hawaii at Manoa, but that collaboration never materialized for at least 2 reasons:

1. Our Co-PI at SMU was assigned a different course to teach just before the fall semester started, and a substitute instructor was assigned to the student team for their capstone course. The new instructor was leery of adding the burden of working with a distant team to the project.
2. The SMU team discovered that their available budget was significantly lower than they had anticipated, causing them to re-scope their project and redefine the requirements. They worked hard to complete their tasks for a preliminary design review in October. Once that was passed they were reluctant to risk their project schedule again by collaborating with an unknown team.

The team produced a testable prototype, prepared a final report and gave a presentation to their faculty supervisor. Although some good systems engineering practices were followed by this project, some aspects of risk management and iterative system development were not. It would have been helpful to provide more tutorial material for new instructors, such as the one assigned to this team.

ARMY MONITORING SUBSYSTEM FOR A TRAINING SYSTEM

This project engaged 8 sub-teams of 36 graduate students in systems engineering at MUST. The student teams collaborated in the design of a control system for a wireless immersive training vest monitoring system. Most of the students were part-time distance students scattered throughout North America, but a few were full-time students on the campus at MUST.

Originally the sub-team at the University of Hawaii at Manoa had planned to work with the students at MUST, but they were unable to find a place to contribute. The MUST students did not feel that they had enough time in their schedule to include a separate Verification and Validation effort. Part of their concern was the need to develop software for the monitoring system, an area where the MUST students were weak.

The sub-teams collaborated in the production of a testable prototype. They also produced final reports and gave presentations to their faculty supervisors. All of the MUST sub-teams used good systems engineering practices, including design reviews and overall lifecycle activities. Their course includes a classroom component that teaches the basics of systems engineering each term. Additionally, many of the students were experienced engineers who had practiced systems engineering in their jobs. This course and project helped to solidify their understanding and appreciation of the field.

NAVY DUAL-USE FERRY/HADR KIT PROJECT

This project engaged 3 sub-teams of students: a team of 4 aerospace engineering students at UAH, a team of 2 undergraduate naval engineering students at Stevens, and a team of 4 engineering management students at Stevens.

The naval engineering students from Stevens designed a ferry for use in developing countries, such as Bangladesh, where ferry traffic is common. Unfortunately, many of the current ferries capsize in bad weather due to poor design for local conditions and lax operating procedures, especially overcrowding. The design proposed by the naval engineering students has much greater stability than current vessels, and is better suited for the type of river navigation required. Additionally, the ferry design allows it to transport emergency supplies when needed.

The aerospace students from UAH designed a water purification system that could be transported in a Joint Modular Intermodal Container (JMIC). They constructed a prototype system that demonstrated the feasibility of their design, including meeting space constraints and providing adequate interfaces. They also conducted an analysis of the volume of water that could be treated using their solar and battery powered system. Given adequate sunlight, their system could provide clean water for a small village for several days.

The engineering management students from Stevens provided overall management of the project, including risk management and resource scheduling. They also conducted research to develop complete requirements for the project. One of the project mentors provided a contact in Bangladesh that the Stevens student team contacted to determine several important parameters about river conditions, ferry traffic and social customs of the area.

The student sub-teams met with one another by teleconference to exchange information and discuss plans. The Stevens engineering management sub-team communicated with the project sponsor, relaying information to and from the other sub-teams. At the end of the project all of the students and their faculty advisors met with the project sponsor and mentors at the Stevens campus in Washington, DC. At that meeting the students displayed their prototype HADR kit and demonstrated its feasibility. The combined teams gave a presentation to the sponsor, the mentors and the faculty. Each team also prepared a final report.

Each of the sub-teams followed good systems engineering practices, including design reviews. The UAH team met with their instructor each week where they had a chance to discuss systems engineering concepts, and they were given a template schedule adapted from NASA's guidebook on systems engineering.

PHASE 3/GUIDELINE PREPARATION

This section of the report summarizes progress made during the third phase of the project.

The original plan had been to conduct a workshop with all of the faculty instructors at the end of the academic year to discuss lessons learned. However, it was not possible to find a time when all of the faculty could meet, so the PI exchanged email with them individually and followed up by phone and personal contact. For the Navy Dual-Use Ferry/HADR Kit project the PI met by Webex with all faculty involved.

Several useful lessons learned were distilled from these conversations. They are reported in the next section. Additionally, a recommended template schedule for multidisciplinary systems engineering capstone projects was created. The schedule should provide sufficient guidance to instructors to ensure that students use good systems engineering practices throughout their projects. The template also provides flexibility for additional requirements to be added to meet program-specific needs. For example, programs that need to perform extensive verification and validation activities on prototype solutions may include that in their schedules.

A new marketplace website was created in response to some of the lessons learned from the use of the pilot system. The new system was developed with more robust technology and is much easier to use from the systems administration side. Some of the improvements made include:

- an executive summary of the capstone marketplace project on the front page
- a Frequently Asked Questions (FAQ) page for students and faculty
- a sponsor-provided graphic for each project proposal
- a standard format for proposal descriptions
- online forms for student and faculty applications

LESSONS LEARNED AND RECOMMENDATIONS

This section provides recommendations for future efforts in this area.

ENLISTING PARTICIPANTS

Capstone projects are solicited and defined in the spring semester at many schools. Some academic programs try to have all their students assigned to teams before they leave campus for the summer. In some cases projects actually start with student internships that take place during the summer before the senior year. If the marketplace hopes to compete within this environment it must have projects ready for review and selection by April at the latest, but even earlier would be better. We hope to have some projects available for review in January this coming year.

Before making proposals, project sponsors need to consider issues of intellectual property, available resources to support student teams, and scope of potential projects. Examples of past projects, including proposals, intellectual property agreements, project schedules and final presentation materials would be of great help to potential project sponsors. These same artifacts are also an aid to students and faculty in planning and starting new projects. The website registry should have a collection of these artifacts for review and adaptation by other projects. There is a place designed for this in the new website system, but we do not yet have any artifacts except a template schedule. We plan on providing several of these artifacts over the next academic year. We also plan to include some results from the pilot student teams.

WEBSITE REGISTRY SYSTEM

We were fortunate to have an existing web-based system that had many of the features we needed for our website registry. Modifying that software was the only feasible strategy we had when the pilot started. However, the software proved to be quite fragile and difficult to modify for our use. It was, after all, only a prototype constructed by a small team of students. In order to have a trustworthy system to use in the future we needed to create a new version from a fresh start.

Some proposed features of the registry system were not available in the pilot project, and they are still not yet available in the new system. For example, students are not able to record comments about projects or potential teammates in the registry. Sponsors are not able to view student applicants to their projects. These features should be implemented and tested in a future version of the registry.

TEAM FORMATION

Although the marketplace concept allows for participation by individual students at different schools it is much easier to engage sub-teams of students, where each sub-team is co-located and supervised by a common faculty member. This fits more easily with existing faculty-student teaching relationships, and it provides more security and robustness in student interactions. Teams of sub-teams also allow for larger projects, which are more realistic examples of multidisciplinary systems engineering.

FUNDING

The marketplace concept allows for multiple types of projects and sponsors. Some sponsors are able to provide funding for student materials and supplies, while others are not. Student teams need to know their budget before starting, and their school contracting offices need to have agreements on hand at the start of the fall term, even though most student teams will not be ready to spend their funds until the spring academic term.

PROJECT ENGAGEMENT AND COOPERATION

Project planning and initiation are crucial to the success of these projects. Especially in cases where teams from different schools collaborate it would be best if faculty (and other stakeholders) met before the project starts to prepare for a kickoff meeting of the students. They should decide what type of collaboration is needed, and agree on expectations of each sub-team.

Faculty should point out to students that collaborative projects are more challenging, but they are also good learning experiences. Lessons they learn will translate to useful points on their resumes and stories to tell during job interviews. Faculty should also explain team dynamics to students and remind them about those during the project.

The students should meet one another at a kickoff meeting of all team members. A face-to-face meeting would be ideal, or a video virtual meeting could be held. During the meeting the stakeholders (or faculty) can present the problem and some expected results. Students can volunteer for roles, and faculty can help set expectations for sub-team responsibilities. After the meeting each sub-team should share their summary of their understanding of the results of the meeting, including their expected roles and responsibilities, with other sub-teams.

During the project each sub-team should meet at least weekly, and each sub-team should communicate with other sub-teams at least weekly. Each sub-team may elect to assign a communication role to a liaison member of their sub-team to simplify communication between sub-teams and mentors. Gantt charts and timelines for sub-team tasks are useful artifacts for sub-teams to share during the project.

A mid-term review and a final review should be held with the whole team each academic semester. These are good opportunities to involve the stakeholders and mentors. Students should be reminded that they need to meet their deadlines, even though their products may not always be perfect.

ROLE OF CLIENT AND MENTORS

Interaction with clients, mentors and other stakeholders is an important part of the capstone experience. Regular meetings should be scheduled, perhaps monthly, to ensure that students have some minimal level of interaction. Stakeholders should be invited to all reviews.

ROLE OF FACULTY

Faculty should meet regularly with their teams, especially at the beginning and end of each term. A weekly schedule is best. During these meetings students can report status, report current challenges and share proposed solutions to problems.

STUDENT EXPERIENCE AND LEARNING

Collaborative projects provide a more realistic experience for students, and they offer more opportunities for students to observe and apply systems engineering techniques. The extra challenges encountered with communication and coordination are balanced by the extra benefits of learning offered by these projects.

RECOMMENDED TEMPLATE SCHEDULE

The following table shows the expectations of multidisciplinary systems engineering capstone projects. We assume that each project is two semesters long. Dividing each semester in half produces 4 half-terms of equal length.

Time Period	Activity	Deliverable
First half-term	Stakeholder identification	List of stakeholders and their expected roles
First half-term	Problem identification	Problem statement
First half-term	Risk identification	Description of potential project risks
First half-term	Project planning	Preliminary project plan
Second half-term	Requirements analysis	Requirements specification
Second half-term	Market study	Description of competing or enabling products
Second and third half-terms	Design exploration	Ranked list of alternative designs
Third half-term	Design specification	Description of proposed design solution
Third and fourth half-terms	Design implementation	Prototype solution
Fourth half-term	Presentation preparation	Demonstration of prototype
Fourth half-term	Project reflection	Final report of project

Each project should have at least 4 reviews:

Time Period	Review	Participants
End first half-term	Preliminary Project Plan	Faculty and students
End first semester	System Requirements	All stakeholders
Third half-term	Preliminary Design (if possible)	Key stakeholders
End third half-term	Critical Design	Key stakeholders
End second semester	Project Conclusion	All stakeholders

Some projects may choose to include other activities, deliverables and reviews. For example, some projects may create a CONOPS during the requirements analysis phase, while others may perform tests and evaluations of their prototype solutions at the end of the project. Similarly, some projects may choose to include more participants in their reviews than the minimum list suggested above.

CONCLUSION

As expected, we were more successful in some areas than in others on this pilot project. Given the late start in acquiring project proposals and engaging students and faculty, we still learned quite a bit from the project.

The pilot was successful in:

- finding several good projects and sponsors
- providing a registry website for students to review project proposals and to post their qualifications
- creating an interesting 3-way collaboration on one project

Faculty and students made good use of the registry website to find projects. In some cases students found projects on their own, while in other cases faculty selected projects or guided students in their selection.

The pilot was unsuccessful in:

- allowing students to form their own teams through discovery on the website registry
- providing funding to all schools when they needed it
- creating collaborations between teams for all students

Some of these goals may be met by improving the website, others by engaging sponsors and participating schools earlier in the year. The schools need a budget to give to students at the beginning of the fall term (September 15). Whether or not that means a subcontract is in place varies from school to school.

Faculty provided good advice in planning and conducting future multidisciplinary systems engineering capstone projects. This advice should be condensed into a form to post on the marketplace website for potential student and faculty participants. Some other useful artifacts still need to be collected or created for posting to the website.